

# The Value of Human Engineering in Designing Exploration Spacecraft

*Jennifer Boyer, Johnson Space Center*

*Harry Litaker, Johnson Space Center*

The role of a human engineering team on a major design and development project such as the Orion spacecraft, Space Exploration Vehicle, or Lander is to ensure the design follows a human-centered design (HCD) process. An HCD process supports development of an effective, efficient, productive, and safe design by linking task, crew, and design requirements.

Three major human engineering activities are conducted to ensure human safety and performance when following an HCD process. These activities include:

- **Task analysis:** Definition of the tasks that crew members will perform both nominally and off-nominally, the hardware they will use, and the context of how they will perform the tasks (mission phase, vehicle configuration, time constraints, number of crew members, etc.)
- **Modeling:** Use of Computer Aided Drawing (CAD) models to represent concepts and static physical volumes, and to assess static crew body positions for the various tasks identified in the task analysis. Modeling should be driven by anthropometric and biomechanical requirements.
- **Human-in-the-loop (HITL) evaluation:** Use of physical mock-ups with crew and non-crew subjects to simulate tasks and evaluate the design under mission-like conditions.

Task analyses, modeling, and HITL evaluations each provides unique information about the tasks that the crew members need to perform, potential crew postures for a range of anthropometric sizes, and the acceptability of the design in performing identified tasks. Each activity within the process informs the other. For example, tasks and scenarios identified in a task analysis may be modeled using CAD software to provide guidance on what is needed per task (such as volume, equipment, and cabin configuration), and this may then be validated with crew subjects in an HITL evaluation. Physical testing in mock-ups of increasing fidelity allows for evaluations of crew performance involving dynamic tasks, translations, and coordination involving crew members. HITL evaluations are critical for providing information on how a design impacts crew task efficiency, effectiveness, and satisfaction.

Thus, it is crucial that all three activities—task analysis, modeling, and HITL evaluations—be used throughout the vehicle design process.

## Impact on Design

Early and iterative HITL evaluations are used to identify design and integration problems, improve usability, and reduce cost and schedule impacts. Throughout the Orion design life cycle, numerous focused HITL evaluations have assessed and improved vehicle design. For example, from 2008-2010, human engineering facilitated at least 39 formal evaluations and 49 human factors hardware consultations.

Evaluation of vehicle designs progresses in stages/phases. Early evaluations focus on individual components, and ensure the design supports the concepts of operation. Work then continues to integrate the components within a subsystem, such as evaluating cursor control device operability using a notional procedure and display. With continued refinement of the design, evaluations are integrated at the system level. For example, a vehicle egress evaluation provides data on seat design, strut design, interior volume, and mobility aids. The data collected during each evaluation vary depending on the objectives of the particular evaluation. Human engineering uses quantitative measures (e.g., error rates) and qualitative measures (e.g., subjective workload scales) to provide a complete picture as to how the design impacts human safety and performance.



**Fig. 1.** Suited subject egressing through the Orion side hatch.

## The Value of Human Engineering in Designing Exploration Spacecraft

*continued*



**Fig. 2.** Photos from left to right: Computer Aided Design model of the Orion cabin, suited subjects inside the Orion cabin, and suited subject inside the Orion cockpit.

Several human engineering evaluations have resulted in significant design impacts, either by saving cost or improving usability.

**Example A.** By conducting an early seat egress evaluation for Orion, NASA identified an impediment to egress caused by the location of a support beam, allowing for early rework of the design and thereby saving cost and schedule.

**Example B.** Evaluation of the Orion side hatch height showed that the crew could effectively egress at varying heights in various suit types, allowing the project to make a needed design change to the bulkhead height without an impact to crew safety or performance.

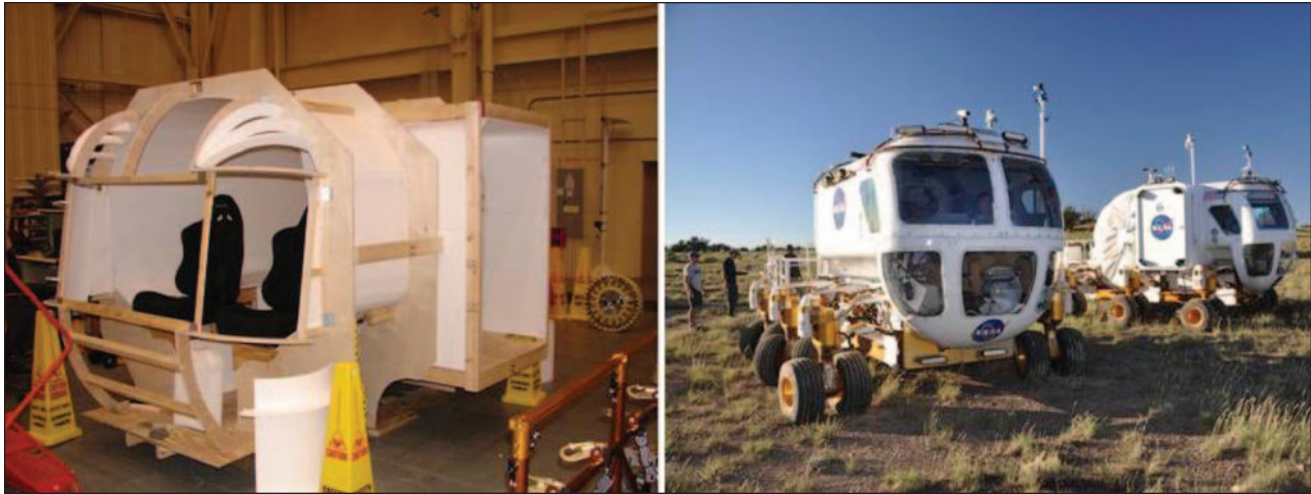
**Example C.** Iterative task analysis, CAD modeling, and evaluation of the Orion crew net habitable volume facilitated requirements progression from a number derived from analysis, to task-driven functional volume assessed through HITL evaluation.

**Example D.** A series of viewability studies identified the need to angle the outer displays, increasing cross-cockpit viewability and crew situation awareness.

**Example E.** Evaluation of the Orion window size and shape early in the design cycle allowed the Orion project to determine the inner and outer mold line without costly adjustments.



**Fig. 3.** Interior configuration of the Altair Lander before and after human factors input.



**Fig. 4.** Progression of the Space Exploration Vehicle from initial to current design.

**Example F.** A seat egress evaluation using various suit types and a range of anthropometric crew sizes identified the need to relocate the Translational Hand Controller from the lower console to the upper console, preventing a snag hazard for the crew.

**Example G.** An HITL evaluation revealed that vehicle stowage for the Altair Lander was inadequate for an extravehicular activity task, impacting performance and increasing crew's workload (left photo). Human factors engineers and vehicle designers improved the stowage by designing suit stowage bags and a hoist system to maximize the upper vertical volume of the vehicle. A follow-up HITL evaluation revealed that crew workload decreased and volume was vastly improved (right photo).

**Example H.** Using data and lessons learned from a functional volume HITL evaluation of 16 dynamic tasks on the Space Exploration Vehicle, vehicle designers updated the cabin configuration—including adding an environment enclosure for spacesuits—and made modifications to window design/placement.

**Example I.** HITL data gathered while a crew of two worked and lived in the functional mock-up of the Space Exploration Vehicle for 3 days proved to be invaluable to vehicle designers. Lessons learned from these simulated missions resulted in a redesign of the cockpit, updated seat adjustment mechanisms, redesigned stowage capacity, and a redesigned trash management system.

## Conclusion

Early, iterative human factors analyses and HITL evaluations provide design and management teams with an enhanced ability to make informed decisions during design and development. Informed decisions reduce costs, and help ensure effectiveness and efficiency for crewed missions.